Journal of Dental Sciences (2012) 7, 130–136

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.e-jds.com

ELSEVIER

Journal of Dental Sciences

ORIGINAL ARTICLE

# Vertical fracture resistance of endodontically treated teeth restored with four sets of obturation and filling materials

**Mastaneh Javaheri [a], Ladan Bahmani-Zanjani [b], Vahid Rakhshan [c], Maryam Foroozia [b*]**

[a] *Department of Operative Dentistry, School of Dentistry, Qazvin University of Medical Sciences, Qazvin, Iran*
[b] *General Practitioner, School of Dentistry, Qazvin University of Medical Sciences, Iran*
[c] *Department of Dental Anatomy and Morphology, Dental Branch, Islamic Azad University, Tehran, Iran*

Final revision received 22 October 2011; accepted 28 February 2012
Available online 15 May 2012

**KEYWORDS**
bonded amalgam-Panavia F;
composite resin;
guttap-percha-AH26;
Resilon-Epiphany;
vertical fracture resistance

**Abstract** *Background/purpose:* Various methods were proposed to increase the fracture resistance of endodontically treated teeth. This study comparatively evaluated the fracture resistance of teeth restored with two obturation and two filling systems.
*Materials and methods:* Forty noncarious single-canal premolars underwent MOD and step-back root-canal cavity preparations. They were randomly divided into four groups of 10 teeth each, according to two categories of coronal restoration (amalgam-Panavia F [A] and composite [B]) and obturation (gutta-percha-AH26 [1] and Resilon-Epiphany [2]). These premolars along with 10 intact control teeth were incubated in 100% humidity (37°C) for 1 week, and then were subjected to compressive forces at a 0.5-mm/min crosshead speed to measure fracture loads. Types of fractures (restorable or nonrestorable) were evaluated under 32× magnification.
*Results:* An ANOVA revealed a significant difference among all groups ($P = 0.000$). According to Tukey's honest significant difference test, there were significant differences only between Groups 1B and 1A, and between 2B and 2A (those restored with amalgam compared to those restored with composite). However, an independent-samples *t* test revealed a significant difference between 1A and 2A as well (gutta-percha-AH26 and Resilon-Epiphany restored with amalgam, $P = 0.027$).
*Conclusions:* Composite-resin restorations may recover significantly more fracture resistance than those bonded with amalgam. Resilon-Epiphany may have slightly but not significantly superior results in terms of fracture resistance.


* Corresponding author. School of Dentistry, Qazvin University of Medical Science, PO Box 34197-59811, Qazvin, Iran.
*E-mail address:* maryam_foroozia@yahoo.com (M. Foroozia).

1991-7902/$36 
doi:10.1016/j.jds.2012.03.009

## Introduction

Endodontically treated teeth might be more susceptible to vertical fractures than are normal teeth.[1–3] Two major reasons may contribute to this, including weakening of the tooth structures following preparation of radicular canals,[4–6] and weakening of coronal structures following preparation of the access cavity.[6,7] The latter seems to be more critical than the former.[6,7] The prognosis of such teeth might be correlated to the radicular/coronal preparation techniques and the amount of tooth tissues removed.[2,8] Among common techniques for improving a tooth's prognosis in terms of its fracture resistance to occlusal loads are indirect restorations with the ability to provide cuspal coverage.[4,9] These require numerous time-consuming and somewhat expensive steps to complete, and may consume intact tooth tissues.[4] Nevertheless, the advent of strong composite resins with bonding agents has enabled clinicians to prepare cheaper, faster, and yet esthetically acceptable direct restorations with partial improvement in the effects on the strength of many root-canal treatment (RCT) cases comparable to indirect restorations.[9,10] Furthermore, the accepted role of bonding agents in increasing the strength and resistance of a tooth to fractures due to the increase in tissue integrity was shown to be favorable.[5,9] This ability of bonding agents has inspired researchers to produce and evaluate similar materials and/or techniques for application in endodontics.[1] These include glass ionomer- and resin-based sealers.[3] Epiphany (Pentron Clinical Technologies, Wallingford, CT, USA) is a dual-cured self-etching composite primer that is used along with the root-canal obturation material, Resilon (Pentron Clinical Technologies), as an alternative to gutta-percha. Unlike gutta-percha in combination with sealers, they can tightly adhere to dentin, probably forming an integrated structure of dentin-composite and increasing the resistance of root walls to fracture.[1,2,11]

Restorative resin-based bonding agents are not limited to composite restorations, and many bonding systems are marketed for use with amalgam.[12–14] Panavia F luting agent (Kuraray, Tokyo, Japan) is one such material for which different results have been reported.[12,14–16] Furthermore, bonded amalgam might increase the fracture resistance similar to what composite resins do.[17,18] On the other hand, controversy exists over the efficacy of resin-based sealers such as AH-26 (Dentsply, York, PA, USA) or Epiphany as well as Resilon filling material to increase a root's resistance to fracture.[2,11,19–25] Even the combination of Resilon-Epiphany has been reported to bond significantly better to dentin than gutta-percha-AH-Plus.[25,26] Williams et al[27] assessed the cohesive strength and stiffness of Resilon and gutta-percha to test whether they are capable of reinforcing root structures. Although Resilon was statistically more reinforcing than gutta-percha, the physical properties of the two materials were so similar that the mentioned difference was clinically inconspicuous. Their findings were supported by Wilkinson et al.[19] To our knowledge, the efficacy of only the strength and resistance of the root structure of such novel RCT materials was evaluated in the literature. The present study was conducted to compare the fracture resistance and fracture types of teeth obturated with Resilon-Epiphany and gutta-percha-AH26, and those filled with a composite resin and amalgam-Panavia F with intact teeth.

## Materials and methods

This experimental *in vitro* study was performed on 50 intact human maxillary single-canal second premolars extracted for orthodontic purposes. The exclusion criteria included the presence of any fractures, caries, restorations, hypocalcification, or hypoplasia; or existence of multiple or lateral canals, calcifications, or severe apical curvature. Periapical radiographs were taken from the buccal and proximal views to confirm that there were no caries, internal resorptions, or calcifications in the root canals. A stereomicroscope (MBC, Russia) was used to search for cracks, multiple canals, lateral canals, calcifications, and external resorption under 8x magnification. In addition, the teeth were macroscopically inspected to try to match sizes with the others. Specimens were sequentially approved until reaching the desired sample size. Each extracted tooth was stored in 0.1% thymol for 48 h and then in normal saline at room temperature until the sample was chosen. This period lasted for a maximum of 3 months.

### Cavity preparation

Control specimens ($n = 10$) were randomly selected from the sample. They remained intact with no preparations. The experimental teeth ($n = 40$), which were randomly distributed among four groups of 10 each, underwent mesial, occlusal, and distal (MOD) cavity preparation with a cylindrical diamond bur (of 0.8 mm in diameter) at high speed, while being cooled with an air-water spray. The dimensions were an occlusogingival depth of 2.5 mm, an axial wall height of 1.5 mm, a buccolingual width of the proximal box on the occlusal side of one-half the intercuspal distance on the isthmus, and a buccolingual width of the gingival floor of the box of three-quarters of the intercuspal distance on the isthmus (Fig. 1). The intercuspal distance was measured with calipers. All measurements were controlled with a periodontal probe during cavity preparation. New burs were used after finishing the procedures on every five specimens.

### Experimental groups

In Group 1A, teeth were obturated with lateral condensation of gutta-percha (Gapadent, Tianjin, Japan) and a resin sealer (AH26; Dentsply), followed by an amalgam restoration (World Work, Montebello Vicentino, Italy) with application of a resin cement (Panavia F, Kuraray).

In Group 1B, the obturation procedure was similar to that of group 1A. A resin composite (Z250; 3M, St Paul, MN, USA) was used along with a 35% phosphoric acid etchant gel (Superetch, 3M) for restoration.

In Group 2A, the root was obturated with lateral condensation of Resilon (Pentron Clinical Technologies) accompanied by Epiphany self-etching primer/sealer

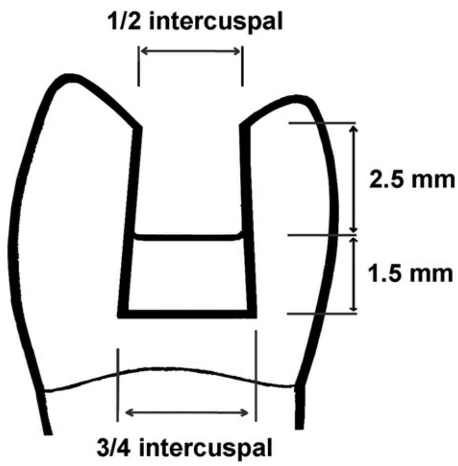


**Figure 1** Dimensions of the MOD cavity.

(Pentron Clinical Technologies). The coronal cavity was filled with amalgam.

In Group 2B, the obturation was performed with a Resilon-Epiphany set, and coronal restoration was performed with a composite.

## Access cavity and root canal preparation

For every tooth, an access cavity was prepared using a low-speed cylindrical diamond bur (with a diameter of 3 mm). To measure the initial working length, a K-file (no. 15, Mani, Tochigi, Japan) was used. It was inserted into the canal until its tip became visible at the apex from a proximal view. This length subtracted by 1 mm was considered the initial working length. The canal was prepared with a step-back method at this length. The apical section was cleaned until a no. 40 master apical file was reached, and the canal was shaped with files up to no. 60. During preparation, the canal was irrigated with a normal saline solution. After using every two larger sizes, patency was maintained with a no. 15 file. When the preparation was finished, the canal was respectively irrigated with 5 ml of 5.25% sodium hypochlorite solution, 5 ml of 17% EDTA (Ariadent, Tehran, Iran),[1,2,11] and 5 ml of a normal saline solution. Then the canal was dried with no. 40 paper points (Meta, Seoul, Korea).

## Obturation

In Groups 1A and 1B (gutta-percha-AH26, $n = 2 \times 10$), the sealer was blended and prepared according to the manufacturer's instructions. It was then applied to the canal walls, using a no. 40 paper point. A master gutta-percha cone (no. 40) was impregnated with sealer and positioned in the canal. Afterward, the canal was obturated with lateral gutta-percha cones (no. 20) using a no. 25 stainless steel finger spreader (Mani). Two periapical radiographs were taken from the buccal and proximal views to ensure that there were no voids. When obturation was accepted, the gutta-percha was cut from 1 mm under the orifice using a heated excavator. Eventually, the canal filling was vertically compacted with a heated plugger, and the orifice was cleaned with alcohol-impregnated cotton wool.

In Groups 2A and 2B (Resilon-Epiphany, $n = 2 \times 10$), the Epiphany sealer mixture, mixed through its tube, was placed on a slab. A no. 40 paper point was used to apply it to the canal walls. A master apical cone of Resilon (no. 40, with a taper of 0.2) was impregnated with Epiphany and inserted into the canal to the working length. Lateral condensation was performed using no. 20 Epiphany-impregnated lateral Resilon cones and a no. 25 finger spreader. After taking periapical radiographs from the proximal and buccal views and ensuring the absence of any voids, the obturation was cut with a heated dental excavator, from 1 mm under the orifice. Then the obturation was condensed with a plugger. The tooth was light cured (40 s) from the occlusal side to provide an immediate coronal seal.

## Restoration

In Groups 1A and 2A (amalgam-Panavia F, $n = 2 \times 10$), each tooth was mounted by its root up to its cementoenamel junction (CEJ) in a cold-curable acrylic resin cylinder. A Tofflemire matrix band was adjusted around the tooth using a matrix holder. Panavia F resin cement was used to bond the amalgam. The luting agent was prepared according to the manufacturer. A thin layer of the mixture was applied to the surfaces. Immediately, a capsule of high-copper amalgam was triturated for 25 s (Mixer 90, Dental Medical, Conegliano, Italy). It was placed and fitted into the cavity. The proximal boxes were filled first. After carving, the matrix band was removed and the restoration was burnished. The excess cement was light cured for 3 s (Ardin Lighting, Tehran, Iran) so that it could conveniently be removed. All restoration margins were then light cured at a 1-mm distance for 20 s per side (occlusal, mesial, and distal). The light-curing unit was calibrated first and again after curing every five specimens to ensure that the light intensity was $>400$ mW/cm$^2$.

In Groups 1B and 2B (composite, $n = 2 \times 10$), the etchant gel was applied to the surfaces. After 15 s, the etched cavity was thoroughly rinsed with an air-water syringe for 30 s. The wet surfaces were carefully dried with cotton wool (wet-bonding technique). They were macroscopically inspected to ensure that they had normal coloration. In case the phenomenon of over drying appeared, the tooth was re-etched. A thin layer of bonding agent available in the composite kit was applied to the enamel and dentin surfaces. It was gently blown for 5 s with an air syringe. A second layer of bonding agent was applied and light cured for 20 s. The composite was placed in the cavity using an incremental technique (each layer was about 2 mm thick). It was first placed in the proximal boxes and then in the occlusal part. When bonding the proximal composites, light was emitted from the buccal and lingual sides. The other parts were light cured from the occlusal side. After adjusting the composite layer to the cavity walls, it was light cured for 40 s. After completely filling the cavity and curing the composite, the excess composite was removed, and the restoration polished using a flame-shaped diamond bur at high speed. Eventually, it was postcured for 60 s.

## Incubation

In order to cure all sealers completely, all experimental and control specimens were incubated at 37°C and 100% humidity for 1 week.

## Measuring the fracture load

Each specimen was mounted upright in a cold-curable acrylic resin cylinder of 3 cm in diameter and a height up to the tooth's CEJ. The apex touched the table during mounting. Therefore, the force passed through the root, preventing fracturing of the resin.

A universal load-testing machine (Instron; Zwick Roell, Ulm, Germany) was used to measure the force. A vertical compressive force was applied to the cusps[1,2,9,10,13–15,23,25] (not to the restoration) using a ball tip 5 mm in radius (Fig. 2), at a crosshead speed of 0.5 mm/min until the force diagram showed a sudden fall. The maximum force was recorded in N as the fracture load.

## Evaluating the fracture types

The teeth were inspected using a stereomicroscope at 32× magnification to determine the location and type of fracture. Fractures that only extended through the enamel and/or dentin were considered restorable. Vertical fractures that passed through the CEJ to the root were determined to be nonrestorable.

## Statistical analyses

Data were analyzed using analysis of variance (ANOVA), Tukey's honest significance test (HSD) test, independent-samples Student's *t* test, and Fisher's exact test. The level of significance was set at $P < 0.05$.

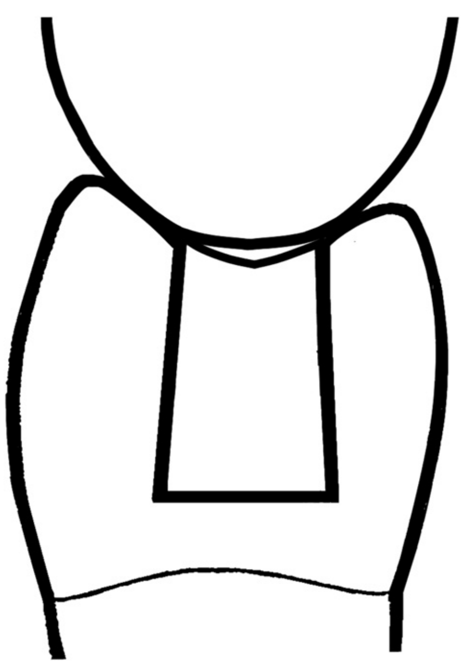

**Figure 2** The load applied is aimed at the cusps not at the restoration.

## Results

The root length was $12.9 \pm 2.1$ mm. The ANOVA showed a significant difference among mean fracture loads in the different groups ($F = 80.3$, $P = 0.000$, Table 1, Fig. 3). Therefore, Tukey's HSD test was used to compare the groups. According to Tukey's HSD (Table 2), the mean fracture load in the control group was significantly greater than values of all experimental groups ($P < 0.05$). It was also significantly greater in Group 1B compared to 1A, and in Group 2B compared to 2A. Generally, the composite groups (1B and 2B) had significantly higher resistance to breakage than the amalgam groups (1A and 2A). The mean breakage load in Group 2A was higher than that in 1A; however, this difference was not statistically significant when calculated with Tukey's HSD. The mean fracture load was also higher but not significantly in Group 2B compared to 1B. According to Tukey's HSD, mean fracture loads in the Resilon-Epiphany groups were not significantly greater than those in the gutta-percha-AH26 groups. Comparing Group 1A to 2A using a *t* test revealed a significant difference ($P = 0.027$), however, Groups 1B and 2B did not differ significantly ($P = 0.306$).

All fractures in the control group were restorable (Fig. 4). Proportions of restorable fractures in Groups 1A, 1B, 2A, and 2B were 20%, 30%, 40%, and 40%, respectively. Nonrestorable fractures occurred through the restoration-tooth interface and extended to the CEJ. Fisher's exact test did not show a significant difference between the proportions of fracture types between Groups 1 and 2 ($P = 0.5$), or between Groups A and B ($P = 1.0$). However, rates of restorable fractures were slightly higher in Groups 2A and 2B than in Groups 1A and 1B. The proportion of restorable fractures in the control group was significantly higher than those of Groups 1 ($P = 0.000$), 2 ($P = 0.002$), A ($P = 0.000$), and B ($P = 0.001$).

## Discussion

Removal of tooth tissues of the coronal and radicular parts is necessary and inevitable during different steps of successful root canal treatment. This might increase the susceptibility of the tooth to fractures. Certain methods were proposed to reverse this, one of which was the use of resin-based filling materials. Physicochemical interactions

**Table 1** Descriptive statistics of the fracture loads of the studied groups ($n = 5 \times 10$).

| Group | Mean ± SD (N) | Min (N) | Max (N) | CV (%) | Mean's 95% CI | |
|---|---|---|---|---|---|---|
| | | | | | Low | Up |
| Control | 1139.5 ± 30.5 | 1086 | 1180.5 | 2.7 | 1117.7 | 1161.3 |
| 1A | 705.0 ± 36.4 | 631.3 | 759.3 | 5.2 | 679.0 | 731.1 |
| 1B | 919.7 ± 64.4 | 808.0 | 1015.0 | 7.0 | 873.6 | 965.7 |
| 2A | 750.0 ± 46.8 | 658.0 | 807.4 | 6.2 | 716.5 | 783.4 |
| 2B | 959.8 ± 101.7 | 836.9 | 1109.7 | 10.6 | 887.0 | 1032.6 |

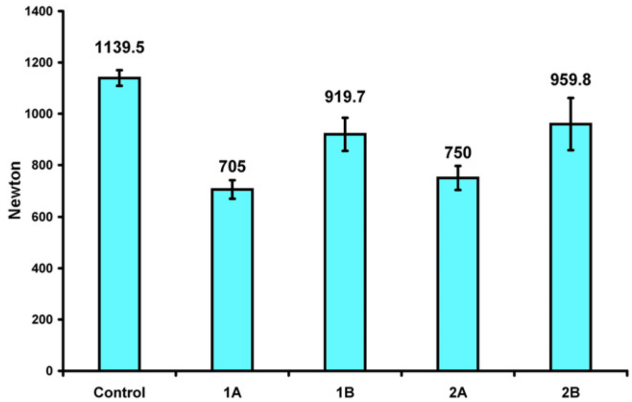


**Figure 3** Mean fracture loads and standard deviations (N) of the studied groups.

**Figure 4** A restorable fracture.

through the tooth-resin interface might lead to a union between the material and tooth, creating a mono-block. This would increase the strength of the root structures; although diverse results were reported.[1-3,28]

In this study, the control group showed the highest fracture resistance, followed by groups that included composite resin restoration, then the amalgam groups. In the composite and amalgam groups, fracture load values for Resilon-Epiphany were slightly higher than those for gutta-percha-AH26. Most fracture types of experimental specimens were nonrestorable. The proportion of restorable fractures was not significantly higher in the Resilon-Epiphany groups than in the gutta-percha-AH26 groups, and both were significantly lower than the control group. No significant differences were observed between the proportions of fracture types between the two restoration materials. The resultant coefficients of variation evidenced the uniformity of the reported mean fracture loads in all groups. Specimens were carefully matched in terms of size; and the techniques were standardized to reduce confounding variables. Root lengths, which could affect the fracture resistance, were nearly uniform among specimens.[18] All specimens contained a single canal; however, the canal morphologies were not matched. They were stored similarly, and were randomly distributed among the groups. Moreover, cavities were carefully prepared with similar techniques by a single operator, using uniform measurements for the MOD cavities. New burs were used after preparing 5 specimens in order to leave similar smear layers. The smear layer, which might be a critical factor,[28] was removed effectively using sodium hypochlorite and EDTA.[1,2,11] The compressive force was carefully aimed at the cusps on all specimens.

Maxillary premolars were selected since they are appropriate for evaluation of the efficacy of materials to increase their fracture resistance. Their anatomy, function, crown size, and crown/root ratio may make them more prone to fracture than other posterior teeth.[13] Moreover, considering their location in the dental arch, they are subjected to both compressive and shear forces.[5,21] Ultimately, they are also important to esthetics.[5]

The composite resin obturation material, Resilon-Epiphany, slightly increased the fracture resistance in both groups in which it was used, compared to those with gutta-percha-AH26. According to the probability value calculated by Tukey's HSD, this slight increase was not significant. However, the confidence interval bounds calculated for these differences showed quite asymmetrical ranges in both comparisons (Table 2, groups 1A vs. 2A and 1B vs. 2B). This implies that the effect of Resilon-Epiphany might be somewhat meaningful. Therefore, these groups were also compared using an independent-samples Student's $t$ test to evaluate whether or not a statistically significant difference existed outside the bounds of the ANOVA. The $t$ test showed that one of the comparisons might result in a statistically significant difference, while the other remained statistically insignificant. In both comparisons, the Resilon-Epiphany had a higher value, confirming its efficacy. Therefore, clinically speaking, there was a considerable difference between the results for Resilon-Epiphany and gutta-percha-AH26, which could be statistically confirmed by increasing each group's size and/or possibly reducing the standard deviation in future studies. As was stated by other authors,[3,11,19,27,28] in terms of a minute evaluation, a considerable difference was observed in the capacity of Resilon-Epiphany to adhere

**Table 2** Results of the Tukey's HSD.

| Groups | | I - J (N) | P | 95% CI (N) | |
|---|---|---|---|---|---|
| I | J | | | Low | Up |
| Control | 1A | 434.5 | 0.000 | 356.3 | 512.7 |
| | 1B | 219.8 | 0.000 | 141.6 | 298 |
| | 2A | 389.5 | 0.000 | 311.3 | 467.7 |
| | 2B | 179.7 | 0.000 | 101.5 | 257.9 |
| 1A | 1B | −214.7 | 0.000 | −292.9 | −136.5 |
| | 2A | −44.9 | 0.485 | −123.1 | 33.2 |
| | 2B | −258.8 | 0.000 | −333 | −176.6 |
| 1B | 2A | 169.7 | 0.000 | 91.5 | 248 |
| | 2B | −40.1 | 0.595 | −118.3 | 38 |
| 2A | 2B | −209.8 | 0.000 | −288 | −131.6 |

to dentinal walls. However, this was not adequate to elevate the fracture loads to those of the control, or even to those produced by composite resin coronal restorations. These results were in agreement with other studies.[11,28] Based on nearly similar findings, other studies concluded that the Resilon-Epiphany set was promising.[1,2,11] However, such subtle superiority should also be taken into account in a holistic perspective, indicating that it might not fulfill the expectations of such materials for use as coronal composite resin restorations.[3]

Certain factors might have contributed to the slight difference in fracture loads between the two obturation sets. Although RCT might reduce the strength of tooth structures, it plays a minor role compared to coronal weakening due to removal of the marginal and cusp ridges.[6] Therefore, the effect of the obturation material might be compensated for by the low proportion of root strength in the total fracture resistance of the tooth. In addition, the comparison group (gutta-percha-AH26) also included a composite resin sealer, which may have confounded the contrast between the natures of the two obturation sets, and decreased the difference between them. Furthermore, both gutta-percha and Resilon have similarly low moduli of elasticity of about 0.005 to 0.008, respectively, compared to dentin.[28] Another factor is the possible presence of oxygen molecules in the dentinal tubules, which could inhibit the polymerization of resin molecules. In addition, the canal cavity was not thoroughly accessible to the light for inducing the highest polymerization rates. Limited creep of the sealer into dentinal pores might be another factor contributing to the reduced mechanical interlocking between the sealer and dentin. A considerable configuration factor in the canal cavity might have separated the sealer from either dentin or Resilon,[27] weakening the mono-block structure.[3] Finally, the remaining smear layer on the dentinal walls might be another major factor.[28] It should be noted that Resilon-Epiphany can be considered an appropriate alternative for gutta-percha if its similar limitations are taken into account. Additionally, it has certain other advantages such as reducing coronal leakage[3] through bonding to the canal walls and the composite resin.

Similar to results of several other studies, a significant reduction was observed in the strength of teeth with MOD restoration.[6,7] Hence, an appropriate restoration material should be able to diminish this difference and lower the fracture rate.[25] Full cuspal coverage using indirect restorations might partially provide this; among its disadvantages, the most critical might be the removal of intact tooth tissues.[4,10] Direct restorations with composite resin have shown comparable results, but do not need to cut the remaining tissues irreversibly.[9,10] Findings of this study confirmed the efficacy of this brand of composite resin (Z250) in combination with its bonding agent. However, the resin-based Panavia F luting agent failed to increase the tooth strength significantly. This was in contrast to one study,[16] but in agreement with many others.[12,14,15] It should be noted that a negative control group is needed to determine such an inefficiency definitively. Dias de Souza[14] stated that, because it has more fillers, Panavia F might have a smaller shock-absorption potential, which might contribute to its poorer results. Additionally, in this study, precise control over the amount of bonding cement applied was difficult, which could have negatively affected the results.[14] The weaker results for amalgam-Panavia F were well correlated to the characteristics of amalgam. Some authors stated that bonded composite resins might increase the fracture resistance of restored teeth.[9,10] Other studies did not observe a significant difference between resin composites and bonded amalgam restorations.[17,18] These differences might be due to different amalgam/composite types, setting times, bonding agents, tooth types, or other methodological differences, as well as the possibility of human error.[14]

In this study, all teeth resisted much higher *in vitro* compressive forces than the normal masticatory forces (100—300 N) that might be exerted on maxillary premolars.[5] However, the force used in this study fundamentally differed in nature from masticatory forces. While natural forces change rapidly in type, magnitude, and direction, this force was a static compressive force that gradually increased until breakage occurred.[5] In addition, thermocycling and the periodontal ligament were not simulated in this study. Therefore, clinical studies are necessary to evaluate these findings further.[3,5]

## Conclusions

Within the limitations of this study and considering the expectations from a resin material to act like coronal resin restoration materials, both gutta-percha-AH26 and Resilon-Epiphany acted similarly. However, Resilon-Epiphany was slightly superior. It should be used like gutta-percha when financial issues are not an issue.

Using appropriate types of composite resins in posterior restorations can be advantageous over using bonded amalgam restorations and thus is recommended.

## Acknowledgments

We would like to thank Dr Nekouian for expert advice on the experimental procedures, Dr Hamid Rakhshan for statistical revision and designing the schematic figures, and the Farzan Clinical Research Institute for editorial assistance.

## References

1. Teixeira FB, Teixeira EC, Thompson J, Leinfelder KF, Trope M. Dentinal bonding reaches the root canal system. *J Esthet Restor Dent* 2004;16:348—54.
2. Teixeira FB, Teixeira EC, Thompson JY, Trope M. Fracture resistance of roots endodontically treated with a new resin filling material. *J Am Dent Assoc* 2004;135:646—52.
3. Ribeiro FC, Souza-Gabriel AE, Marchesan MA, Alfredo E, Silva-Sousa YT, Sousa-Neto MD. Influence of different endodontic filling materials on root fracture susceptibility. *J Dent* 2008;36:69—73.
4. Shillingburg H, Hobo S, Whitsett L, Jacobi R, Brackett S. *Fundamentals of Fixed Prosthodontics*, 3rd ed. Carol Stream: Quintessence Publishing; 1997.
5. Oskoee SS, Oskoee PA, Navimipour EJ, Shahi S. *In vitro* fracture resistance of endodontically-treated maxillary premolars. *Oper Dent* 2007;32:510—4.

6. Slutzky-Goldberg I, Slutzky H, Gorfil C, Smidt A. Restoration of endodontically treated teeth review and treatment recommendations. *Int J Dent* 2009;2009:150251.
7. Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature—Part 1. Composition and micro- and macrostructure alterations. *Quintessence Int* 2007; 38:733—43.
8. Larson TD, Douglas WH, Geistfeld RE. Effect of prepared cavities on the strength of teeth. *Oper Dent* 1981;6:2—5.
9. Santos MJ, Bezerra RB. Fracture resistance of maxillary premolars restored with direct and indirect adhesive techniques. *J Can Dent Assoc* 2005;71:585.
10. Daneshkazemi AR. Resistance of bonded composite restorations to fracture of endodontically treated teeth. *J Contemp Dent Pract* 2004;15(5):51—8.
11. Hammad M, Qualtrough A, Silikas N. Effect of new obturating materials on vertical root fracture resistance of endodontically treated teeth. *J Endod* 2007;33:732—6.
12. Imbery TA, Coudron J, Moon PC. Fracture resistance of extensive amalgam restorations retained by pins, amalgapins and amalgam bonding agents. *Oper Dent* 2008;33:666—74.
13. Marchan SM, Coldero L, White D, Smith WA, Rafeek RN. Cusp fracture resistance of maxillary premolars restored with the bonded amalgam technique using various luting agents. *Int J Dent* 2009;2009:946830.
14. Dias de Souza GM, Pereira GD, Dias CT, Paulillo LA. Fracture resistance of premolars with bonded class II amalgams. *Oper Dent* 2002;27:349—53.
15. Dias de Souza GM, Pereira GD, Dias CT, Paulillo LA. Fracture resistance of teeth restored with the bonded amalgam technique. *Oper Dent* 2001;26:511—5.
16. Kececi A, Adanir N. Comparison of the fracture strength of various materials used to bond the fragments of oblique fractured pulpless teeth. *SÜ Diflhek Fak Der* 2008;17:35—8.
17. Steele A, Johnson BR. *In vitro* fracture strength of endodontically treated premolars. *J Endod* 1999;25:6—8.
18. Sagsen B, Aslan B. Effect of bonded restorations on the fracture resistance of root filled teeth. *Int Endod J* 2006;39: 900—4.
19. Wilkinson KL, Beeson TJ, Kirkpatrick TC. Fracture resistance of simulated immature teeth filled with resilon, gutta-percha, or composite. *J Endod* 2007;33:480—3.
20. Stuart CH, Schwartz SA, Beeson TJ. Reinforcement of immature roots with a new resin filling material. *J Endod* 2006;32: 350—3.
21. James B, Summitt M, Robbins J. *Fundamentals of Operative Dentistry: A Contemporary Approach*, 3rd ed. Carol Stream: Quintessence Publishing; 2006.
22. Cobankara FK, Ungör M, Belli S. The effect of two different root canal sealers and smear layer on resistance to root fracture. *J Endod* 2002;28:606—9.
23. Hanada T, Quevedo CG, Okitsu M, et al. Effects of new adhesive resin root canal filling materials on vertical root fractures. *Aust Endod J* 2010;36:19—23.
24. Jainaen A, Palamara JE, Messer HH. The effect of resin-based sealers on fracture properties of dentine. *Int Endod J* 2009;42: 136—43.
25. Ulusoy OI, Genç O, Arslan S, Alaçam T, Görgül G. Fracture resistance of roots obturated with three different materials. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007;104: 705—8.
26. Gesi A, Raffaelli O, Goracci C, Pashley DH, Tay FR, Ferrari M. Interfacial strength of Resilon and gutta-percha to intraradicular dentin. *J Endod* 2005;31:809—13.
27. Williams C, Loushine RJ, Weller RN, Pashley DH, Tay FR. A comparison of cohesive strength and stiffness of Resilon and gutta-percha. *J Endod* 2006 Jun;32:553—5.
28. Tay FR, Pashley DH. Monoblocks in root canals: a hypothetical or a tangible goal. *J Endod* 2007;33:391—8.